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Spatial and temporal variability of mangrove ecosystems in the Cu Lao Cham-Hoi An Biosphere Reserve, Vietnam

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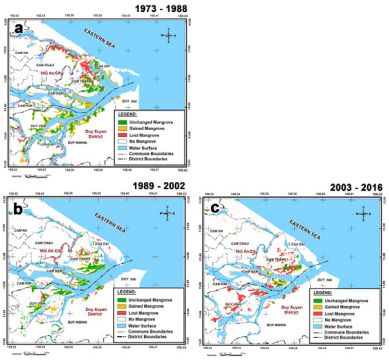
GRAPHICAL ABSTRACT



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ABSTRACT

Mangrove ecosystems in central Vietnam play an important role in protecting the coast line; reducing erosion and salinization; as well as regulating climate. Mangrove ecosystems in Cu Lao Cham-Hoi An Biosphere Reserve contribute significantly to the role of coastal protection, climate change resilience, and local economic development. Historical satellite remote sensing data, intensive field surveys and GIS techniques have been employed in many tropical areas worldwide to detect mangrove changes. The objective of this study is to use Landsat imagery covering the past 44 years (1973–2016) to study historical changes of the mangrove ecosystems in the Cu Lao Cham-Hoi An Biosphere Reserve and to document the current distribution of species diversity in the Reserve's mangrove ecosystems. The field surveys and analysis of satellite remote sensing data revealed that the mangrove ecosystem in Cu Lao Cham-Hoi An Biosphere Reserve has fluctuated significantly in both temporal and spatial distribution. This study has newly documented eight mangrove species to the inventory of the Cu Lao Cham-Hoi An Biosphere Reserve mangroves species composition. This study is regarded as the first study using multi-spectral satellite remote sensing image to assess the distribution status and historical changes of mangrove ecosystems in central Vietnam. The outcomes can contribute to assessing the dynamic trends of coastal ecosystem changes during the past 44 years to provide sustainable development strategies for the area.

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1. Introduction

Coastal wetland ecosystems such as mangroves, seaweedes, seagrasses and coral reefs play important roles in the coastal

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marine environment and coastal communities. Of those, mangrove ecosystems play a central role in the coastal marine environment forming significant habitats of mangrove ecosystems from the land to the coral reef ecosystems of the sea (Graham, 1990; Masahiro, 2007; Nuraini et al., 2007). Mangrove ecosystems form the habitat for feeding, breeding, and growth for coastal and marine organisms (Lobban and Harrison, 1994; Barnes and Hendy, 2015; Dromard et al., 2016). These ecosystems work as a bio-filter, enhancing water quality by the up-take of sediment and inorganic compounds (Abal and Dennison, 1996). Together with phytoplankton, mangroves contribute a significant amount oxygen to the atmosphere as well as absorbing CO_2 via photosynthesis activities (Muraoka, 2004; Aizawa et al., 2007; Chisti, 2007). For coastal communities, mangrove ecosystems are recognized as supplying critical materials for the cosmetic (Hong et al., 2007), pharmacy, and chemical industries (Ali and Gamal, 2010). Finally, these ecosystems contribute to maintaining and protecting the wild fisheries of the coastal communities (Lobban and Harrison, 1994).

Satellite remote sensing has become a powerful technique for monitoring changes and plays a vital role in natural resource management and environment protection (Garcia et al., 2015; Hoang et al., 2015, 2016). There have been numerous studies on mangrove ecosystems using multi-spectral satellite remote sensing data. These studies primarily focused on topics such as mapping the spatial status of mangrove distribution (McCourt, 1984; Iverson and Bittaker, 1986; Hillman et al., 1995; Yuan and Zhang, 2008; Barillé et al., 2010; Guimarães et al., 2012; Carle et al., 2014), and assessing temporal variations (Gullström et al., 2006; Zhu et al., 2007; Díez et al., 2012).

Currently many satellite remote sensing image resources are available without cost from the United States (e.g. Landsat ETM+, 8 OLI) and Europe (e.g. Sentinel 1–2) that have moderate (30 m) to relatively high (10 m) spatial resolution (Hedley et al., 2016). The Landsat satellite images have been used to study the coastal ecosystems such as mangroves, seagrass, and saltmarsh ecosystems since the 1980s.

In Vietnam, studies on the distribution status of mangrove ecosystems along the coastal areas have been carried out since 1990 (Pham et al., 2006). However, most of these studies focused on assessing the species composition (Tran and Luong, 2012) and the distribution status (Phan and Populus, 2007; Nguyen, 2009; Ton et al., 2009; Hoang et al., 2010). Nevertheless, at present, the data of distribution status, community structures and biomass quantification of mangrove ecosystems are still limited by its incompleteness, nonsystematic collection and spatial properties. To date, there are no studies on temporal changes of mangrove ecosystems in central Vietnam using Landsat satellite remote sensing images.

The major objective of this study is to contribute to establishing the ecological database of mangrove ecosystem changes in Cu Lao Cham-Hoi An Biosphere Reserve, on the central coast of Vietnam, using multi-temporal Landsat satellite image data. The specific objectives of this study were as follows: *(1)* establishing the database on species composition of mangrove ecosystems in Cu Lao Cham-Hoi An Biosphere Reserve, central Vietnam; *(2)* constructing the database of temporal changes on the distribution area of mangrove ecosystems using multi-spectral satellite sources during the period of 1973–2016; and *(3)* assessing the impact of major factors that are the drivers of mangrove ecosystem changes to sustainably develop and manage these resources.

2. Materials and methods

2.1. Study area

Cu Lao Cham-Hoi An Biosphere Reserve is located in Quang Nam province, central Vietnam with geographic coordinates 15°49′37″–15°55′1″N and 108°19′1″–108°25′55″E. This area belongs to the Cu Lao Cham Biosphere Reserve, which includes Hoi An city and Duy Xuyen district, Quang Nam province (Fig. 1). Cu Lao Cham-Hoi An Biosphere Reserve coastal area generally slopes from the northwest to the southeast with an average slope of 0.015 degrees (Hoi An PC, 2015). Topography and geomorphology of the Cu Lao Cham-Hoi An Biosphere Reserve coastal area is diversified including the ancient city of Hoi An, a new urban area, the world cultural heritage site of My Son, coastal delta, sea, islands and mountains with diverse forestry and fishery resources. Total forest area of Cu Lao Cham-Hoi An Biosphere Reserve is approximately 183.47 ha (Hoi An city has 82.95 ha, Duy Xuyen district has 100.52 ha), including special-use forest and protected forest (Hoi An PC, 2015). The forest here is unique with diverse fauna and high biosphere reserves. Special-use forests are concentrated in Cu Lao Cham archipelago, displaying the characteristics of tropical forests with hundreds of species belonging to flowering plant families, which are identified in the list of medicinal plants (Vu and Dinh, 2015). Protected forests are mainly distributed along river and coastal areas. In addition to landscape beauty, the protected forests also play an important role in coastal protection, wave and wind protection and erosion control (Kathiresan and Rajendran, 2005).

2.2. Data collection

Secondary data relating to mangrove ecosystems was collected from the master planning reports on socioeconomic development and natural resource management, issued at provincial, districts, and commune levels; annual and five year reports on socioeconomic activities by local authorities at Cu Lao Cham-Hoi An Biosphere Reserve, Hoi An city; and available land use and coastal natural resource maps from the Department of Natural Resources and Environment as well as related scientific, technical project reports and annual statistical yearbooks of the study areas (Vu and Dinh, 2015; Hoi An PC, 2015).

Landsat multi-spectral satellite remote sensing images listed in Table 1 were downloaded from the United States Geological Survey (USGS) Earth Explorer internet portal, stored and analyzed for this study.

2.3. Methodology

2.3.1. Assessing the species composition and distribution status of mangroves ecosystems

Two ecological tools, transects and quadrats, were used to quantify the relative abundance of mangrove species composition. The study transects were identified prior to the field surveys based on the bathymetry and base maps of the coastal water areas. Motorboat and motorbikes were used to conduct surveys of the coastal area at Duy Nghia, Cam Thanh, Cam Chau and Cam Nam communes. During survey trips, Global Position System (GPS) receivers (Garmin-eTrex® 10, U.S.A) were employed to determine the distribution areas of mangrove ecosystems as well as to identify the ground-truthing points for satellite remote sensing image analysis and interpretation (Fig. 2). Geographical Information System (GIS) technology was used in collection, management, analysis and visualization of the distribution status of mangroves ecosystems using the World Geodetic System (WGS-84) as the reference coordinate system. The ground-truthing points were also used for satellite georeferencing and validation. A total of 140 ground-truthing points were acquired during four field survey trips in March, April, August 2017 and January 2018.

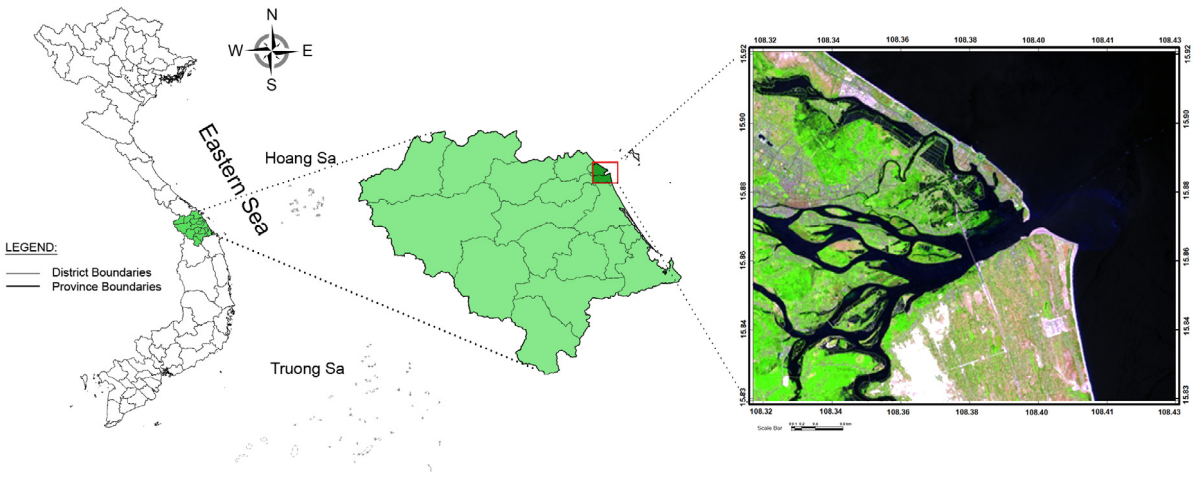

Fig. 1. Location map of study area, Cu Lao Cham-Hoi An Biosphere Reverse in central Vietnam.

Table 1
Landsat imagery used for mangrove change detection.

Year	Satellite sensor	Image ID	Acquired date	Spatial resolution (m)	Path/row
1973	Landsat	LM11330491973181AAA05	30.Jun.1973	60	133/49
1988	Landsat	MTN-49-15_LOC	08.Jun.1988	30	124/49
1989	Landsat	MTN-48-15_LOC	08.Jan.1989	30	124/49
2002	Landsat	LE07_L1TP_124049_20020801_20170128_01_T1	01.Aug.2002	30	124/49
2003	Landsat	LE07_L1TP_124049_20030414_20170125_01_T1	14.Apr.2003	30	124/49
2016	Landsat	LC08_L1TP_124049_20160714_20170323_01_T1	14.Jul.2016	30	124/49

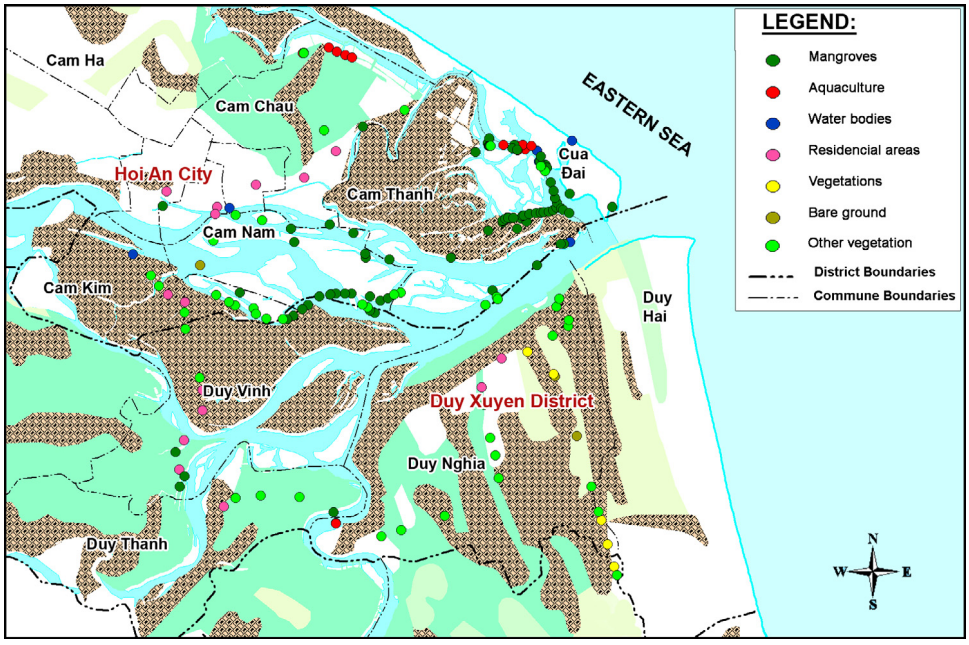

Fig. 2. The ground truth points collected at Cu Lao Cham-Hoi An Biosphere Reserve — Hoi An city and Duy Xuyen district, Quang Nam province.

2.3.2. Mangrove species identification

On location, elements (leaves, flowers, fruits) of a tree that did not change shape and color were used to determine its species. When species could not be determined, samples and pictures were taken. Samples were arranged neatly, put in nylon bags, pressed and desiccated. Samples were pressed between two paper layers then arranged with an identifying number on two pieces of wood (15–20 cm thick) and strongly tied. After pressing, samples were exposed to the sun and paper layers were frequently changed.

The mangrove specimens were identified on the basis of the local literature (Phan and Hoang, 1993; Pham, 1999; Giesen et al., 2006). The temporal and spatial distribution characteristics of mangrove ecosystems were studied according to the acquired ground truthing points and classifications.

2.3.3. Community survey method

Structured and semi-structured interviewing methods were used to interview household representatives on perceptions of people about roles, status, change of mangroves, socio-economic activities impact on mangroves and management status. In order

to collect historical information, the selected interviewers were people in communes and wards who were 50 years or older.

The study used a stratified random sampling method to interview local people. Cam Thanh, Cam Chau, Cam Nam (Hoi An City) and Duy Nghia (Duy Xuyen District) communes were selected for interviews. There were 103 questionnaires (28 questionnaires in Cam Thanh, 21 questionnaires in Cam Nam, 23 questionnaires in Duy Nghia, 9 questionnaires in Duy Vinh and 22 questionnaires in Cam Chau). Interview data were stored and process by MS. Excel v. 2010 software.

2.3.4. Laboratory analysis

Remote sensing and QGIS 2.18.14 software were used in analysis and processing of multi-spectral satellite remote sensing imagery. Remote sensing data and GIS technology were used to create a map of the current distribution of mangrove areas during the period 1973–2016. The workflow is shown in Fig. 3.

The satellite remote sensing images after collection were analyzed and processed through steps such as band match, image resize, enhancing, spectral math, and supervised classification.

During the four field trips in March, April, August, 2017 and January 2018; characteristic parameters of the 140 key points were collected, divided into seven land use and land cover classes including water bodies, aquaculture, mangroves, residential areas, vegetation, bare ground, and other vegetation (Fig. 2). The vegetation layer includes land used type for the purpose of planting short-term crops such as corn, sweet potatoes, and beans. The layer of other vegetation includes banana trees, rice plants, coconut trees, in which rice plant is dominate. Based on the data in the key point set, classification was initiated using a maximum likelihood method that was selected for this study. By selecting sample points, the analyst determined the pixels with the same shape of reflectance spectra. The maximum probability algorithm assumes that the pixels were to be classified in the class that is of the highest probability. Seven land-use types were defined, each with different reflecting characteristics. This algorithm is considered as the most commonly used method in remote sensing image processing for classifying vegetation cover. This method results in accurate interpretation but requires time-consuming calculations, depending on the standard distribution of the data and the experience of the analyst (Asmala, 2012; Hogland et al., 2013).

The confusion matrix evaluation methods and Kappa coefficient (κ) were used in assessing the accuracy of the classification and interpretation results of satellite remote sensing images (Congalton, 2001; Congalton and Green, 2009). The matrix evaluation methods and Kappa coefficient (κ) is frequently used in assessing the accuracy of classification and interpretation of satellite remote sensing images (Stehman, 1996; Congalton and Green, 2009). Overall accuracy and Kappa coefficient (κ) evaluated the significant differences between classifications. In the matrix evaluation, overall accuracy is calculated by the ratio of the total number of correctly classified pixels and the total number of misclassified pixels. The Kappa coefficient ranges from 0 to 1 (Congalton, 1991). Field survey data were used to assess the classified and quantified results' accuracy. This index is usually expected to be larger than 0.7 to assure reasonable outcomes.

After the classification results ensured the desired accuracy, QGIS 2.18.14 software was used to prepare mangrove's distribution data and change area maps for 1973, 1988, 1989, 2002, 2003 and 2016. The mangrove forest area assessment for the study area was divided into three periods: 1973–1988, 1989–2002, and 2003–2016.

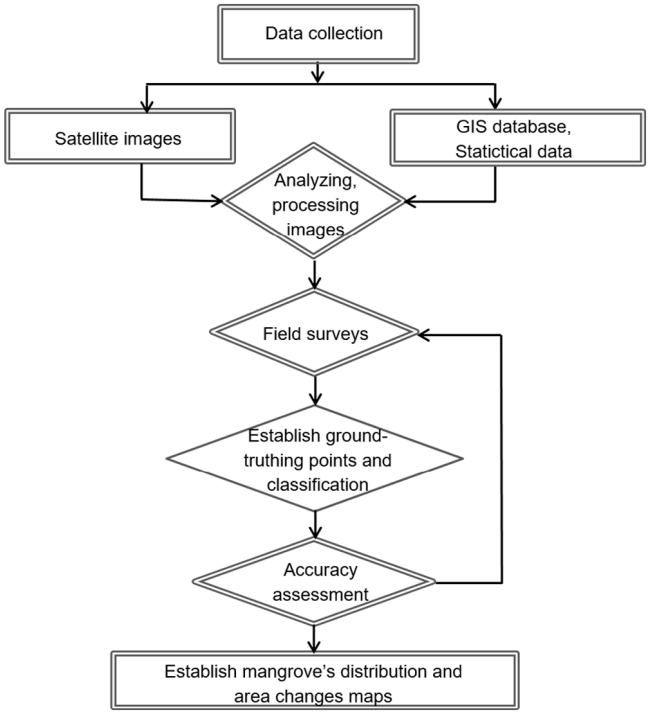

Fig. 3. The workflow to create the maps of temporal change of mangrove ecosystems.

3. Results

3.1. Database on species composition of mangroves

The survey results regarding the mangrove ecosystems at Cu Lao Cham-Hoi An Biosphere Reserve identified 16 mangrove species from 16 genera, 14 families and 2 vascular plant species. Of those, Magnoliophyta dominated with 13 families, 15 genera and 15 species and Polypodiophyta was identified as only one species and one family. There are 9 true mangrove and 7 associated mangrove species in the total of 16 identified mangrove species. According to Phan (1999), 35 true mangrove and 71 associated mangrove species belonging to 47 families have been found in the coastal areas of Vietnam (Phan and Hoang, 1993). Compared to Phan's study (1999), the proportion of true mangroves was low with 25.7% (9/35) of the total true group found in Vietnam. The associated mangroves accounted for 9.9% (7/71) of the total associated mangrove species in Vietnam.

3.2. Geoinformatic database of the distribution area of mangrove ecosystems

In Cu Lao Cham-Hoi An Biosphere Reserve, the satellite-derived estimation of the area of mangrove forest was 105.3 ha. *Nypa fruticans* was the most common species in the study area and the mangrove forest was mainly distributed in Cam Thanh commune. Results of the distribution of mangrove forest area from 1973 to 2016 is presented in Table 2.

Table 2 shows the fluctuation in mangrove area during the study periods. By 1988 the total area of mangrove had decreased by 29.6% when compared to 1973 (207.3 ha). From 1989 to 2002, the total area of mangrove lost was 35.6% compared to 1989 (117.2 ha). Between 2003 and 2016, the mangrove forest area continued to decrease by approximately 66.7% (210.7 ha). Thus, the total area of mangrove forest in the study area suffered a significantly decline during the last 43 years (Fig. 4 a–f). It

Table 2
The dynamics of mangrove ecosystems area changes in Cu Lao Cham-Hoi An Biosphere Reserve from 1973 to 2016.

Areas/ District	Commune	The area of mangrove forest (ha)								
		1973	1988	Dynamic rate (%)	1989	2002	Dynamic rate (%)	2003	2016	Dynamic rate (%)
Hoi An City	Cam Thanh	245.97	147.02	−40.23	160.31	150.30	−6.24	144.27	75.78	−47.47
	Cam Chau	81.63	19.35	−76.30	16.66	1.71	−89.74	2.79	3.87	+38.71
	Cua Đai	48.69	37.17	−23.66	21.76	3.23	−85.16	7.65	1.17	−84.71
	Cam Nam	28.80	33.12	+15.00	24.75	15.39	−37.82	14.94	2.70	−81.93
	Cam Ha	23.76	3.33	−85.96	20.91	0.01	−99.95	0.63	0.36	−42.86
	Cam Kim	15.84	7.47	−52.84	13.74	12.06	−12.23	14.22	0.10	−99.30
Duy Xuyen	Duy Vinh	146.89	138.33	−5.23	152.60	107.1	−29.82	101.13	12.86	−87.32
	Duy Nghia	82.80	74.79	−9.67	44.51	17.80	−60.01	26.27	8.37	−68.14
	Duy Thanh	24.48	27.63	+12.87	42.66	13.22	−69.01	4.14	0.10	−97.58
	Duy Hai	1.62	4.95	+205.56	0.10	0.00	−100.00	0.00	0.00	0.00
Total		700.48	493.16	−29.60	498.0	320.82	−35.58	316.04	105.31	−66.68

Notes: (+ Increase, − Decrease area).

Table 3
The matrix of classification results 1973 (Unit: pixel) – Kappa coefficient = 0.94.

	Water bodies	Mangroves	Aquaculture	Other vegetation	Residential areas	Vegetation	Bare ground	Total by column
Water bodies	**6126**	0	0	0	0	0	6	6 132
Mangroves	7	**112**	0	23	0	0	0	142
Aquaculture	0	0	**0**	0	0	0	0	0
Other vegetation	0	3	0	**2731**	9	1	0	2 744
Residential areas	9	4	0	102	**321**	173	0	609
Vegetation	0	0	0	8	83	**587**	54	732
Bare ground	39	0	0	1	2	16	**1941**	1 999
Total by row	6181	119	0	2865	415	777	2001	**12 358**

Overall accuracy = (11818/12358) = 95.63%.

was determined that the area of least change was the Bay Mau forest in Cam Thanh commune. In contrast, the most vulnerable communes where losses occurred were in Duy Xuyen district including Duy Vinh, Duy Thanh and Duy Nghia communes.

3.3. Accuracy assessment of classification results

Classification results sometimes create image products that have errors in some pixels. These errors lead to misleading results; in classifying photos from 1973, there were appearances of mangrove pixels in the water bodies (7 pixels) or residential area pixels (9 pixels) or bare ground (39 pixels) in water bodies. Subsequently, the matrix of classification results assessment and reality map was created (Table 3).

The pixels on the diagonal are correctly classified pixels, the off-diagonal pixels are considered to be misclassified. Due to the counts of correct pixels, total misclassified pixels, and total pixels it was possible to calculate overall accuracy and Kappa coefficient. Similar to 1973, Kappa coefficient and overall accuracy of the years 1988, 1989, 2002, 2003, and 2016 are shown in Table 4.

The results of the mangrove forest mapping yielded rather high accuracy ($\kappa = 0.81$). The highest result of classification was in 2016 ($\kappa = 0.95$) and the lowest was in 1989 and 2003 ($\kappa = 0.88$). The Kappa coefficient and overall accuracy of 1973, 1988, and 2002 were quite high. However, these values were still lower than 2016 because it was not possible to collect data at GPS points for those years. The maps of 1989 and 2003 had the lowest Kappa coefficient and accuracy overall, apart from the reason above, it was also affected by cloud coverage that caused errors because data from GPS points could not be collected due to the clouds in this image.

3.4. The temporal changes of mangroves ecosystems over the period of 1973–2016

The statistical results of lost, gained and unchanged mangrove areas were used to prepare the maps of temporal change in Fig. 5. The area of lost mangroves was greater than the area of mangrove gains. In the period from 1973 to 1988, the total area of lost mangrove was 476.37 ha while the total area of new mangrove in Cu Lao Cham-Hoi An Biosphere Reserve was 269.05 ha (Fig. 5a). The mangrove area continued to decrease during the period from 1989 to 2002. The loss was 293.15 ha while the gain was 115.97 ha (Fig. 5b). Between 2003 and 2016, the total area of lost mangrove was 256.64 ha and the gain was 45.91 ha (Fig. 5c).

Table 4
Kappa coefficient and overall accuracy of classification results from 1973 to 2016.

Year	Kappa coefficient (κ)	Overall accuracy (%)
1973	0.94	95.63
1988	0.94	96.00
1989	0.88	92.41
2002	0.92	95.42
2003	0.88	93.24
2016	0.95	97.01

3.5. The effects of key environmental and social-economic parameters on the temporal changes of mangrove ecosystems

According to the results of household surveys in the study area, the major identified reasons for mangrove forest fluctuation/dynamics are shown in Fig. 6 followed by comments on each reason.

Deforestation for building resorts and houses (56.9% of responses): In recent years, ecotourism activities and handicraft processing have become more popular. The demand for handicraft products has increased rapidly, so the exploitation of products' materials also increased. It is shown that several mangrove areas have been encroached on by ecotourism businesses and handicraft production (Fig. 7a).

Exploitation for firewood and house construction materials (23.6% of responses): *Nypa fruticans* leaves are gathered twice a year in March and July. However, *Nypa fruticans* leaves can be exploited more than twice a year, depended on the material demand. Due to the economic benefits, many farmers have

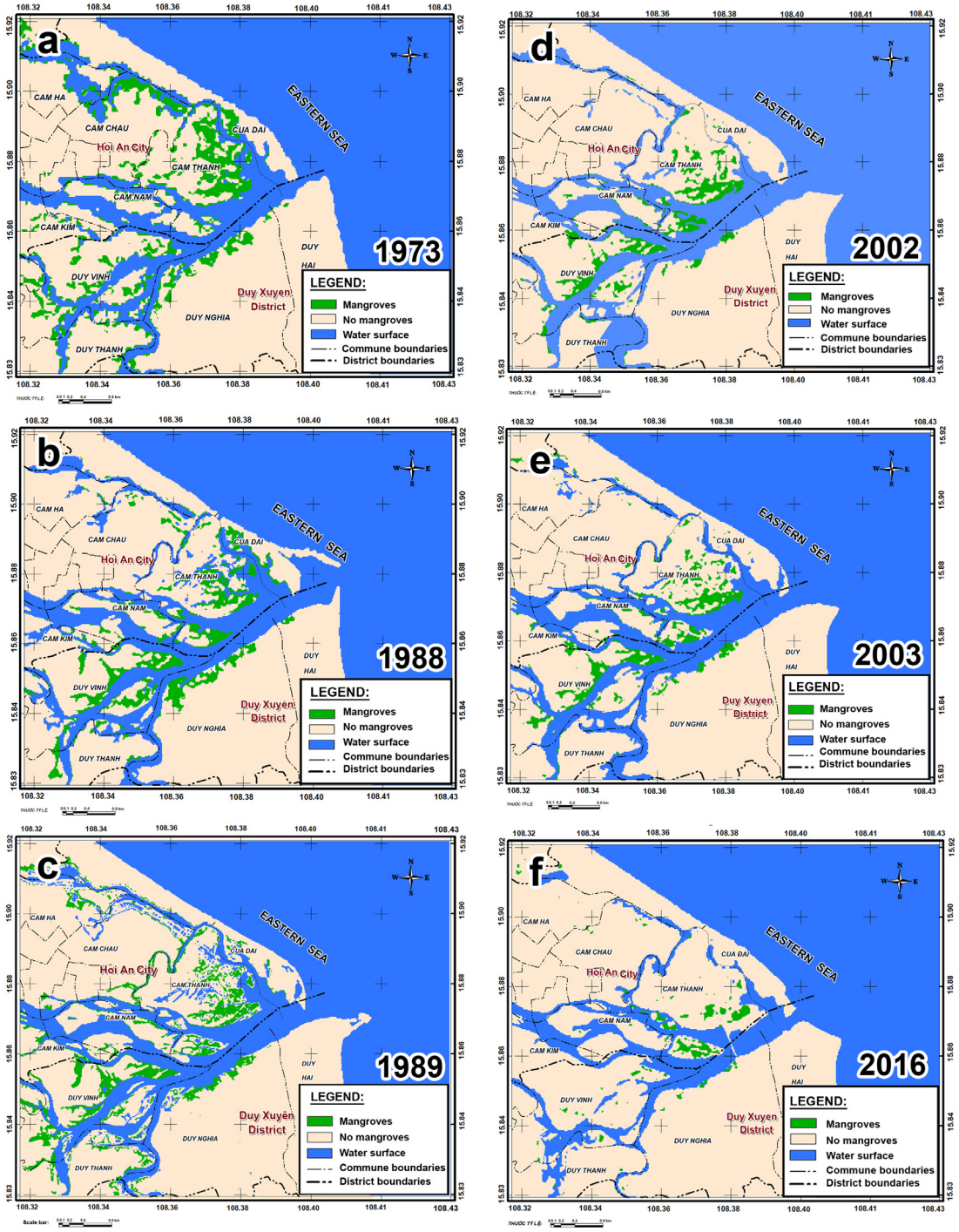

Fig. 4. The maps of distribution of mangroves in Cu Lao Cham-Hoi An Biosphere Reserve from 1973 to 2016: (a) 1973, (b) 1988, (c) 1989, (d) 2002, (e) 2003, and (f) 2016.

over exploited *Nypa fruticans* leaves which affected mangrove ecosystem's health (Fig. 7b).

Coastal erosion and floods (22.2% of responses): In the past 40 years, Thu Bon river banks in Duy Xuyen district have suffered severe erosion. Thu Bon watershed floods from September to November annually. Mangroves were usually distributed along the riverbanks so erosion, floods, and tropical cyclones have damaged these areas of mangrove (Fig. 7c).

Deforestation for building shrimp ponds (16.7% of responses): After 1975, the campaign for restoring the local economies turned many mangrove forests into salt fields. However, due to low economic efficiency, parts of the salted land were converted to shrimp ponds and the remaining land was abandoned. Then the shrimp ponds were greatly expanded in the study area and local people destroyed more of the mangrove forest for shrimp ponds, further diminishing the mangrove forest area. The socio-economic development by local residents has destroyed a significant area of mangroves in the region (Fig. 7d).

Deforestation for building ports and other construction (8.3% of responses): Declination of mangroves was partly due to land use changes of building construction projects to facilitate the local economy. In particular, the construction of Cua Dai Bridge and its linking roads in 2012 and a fishing dock constructed in 2013 had a significant impact on mangrove deforestation in the study area.

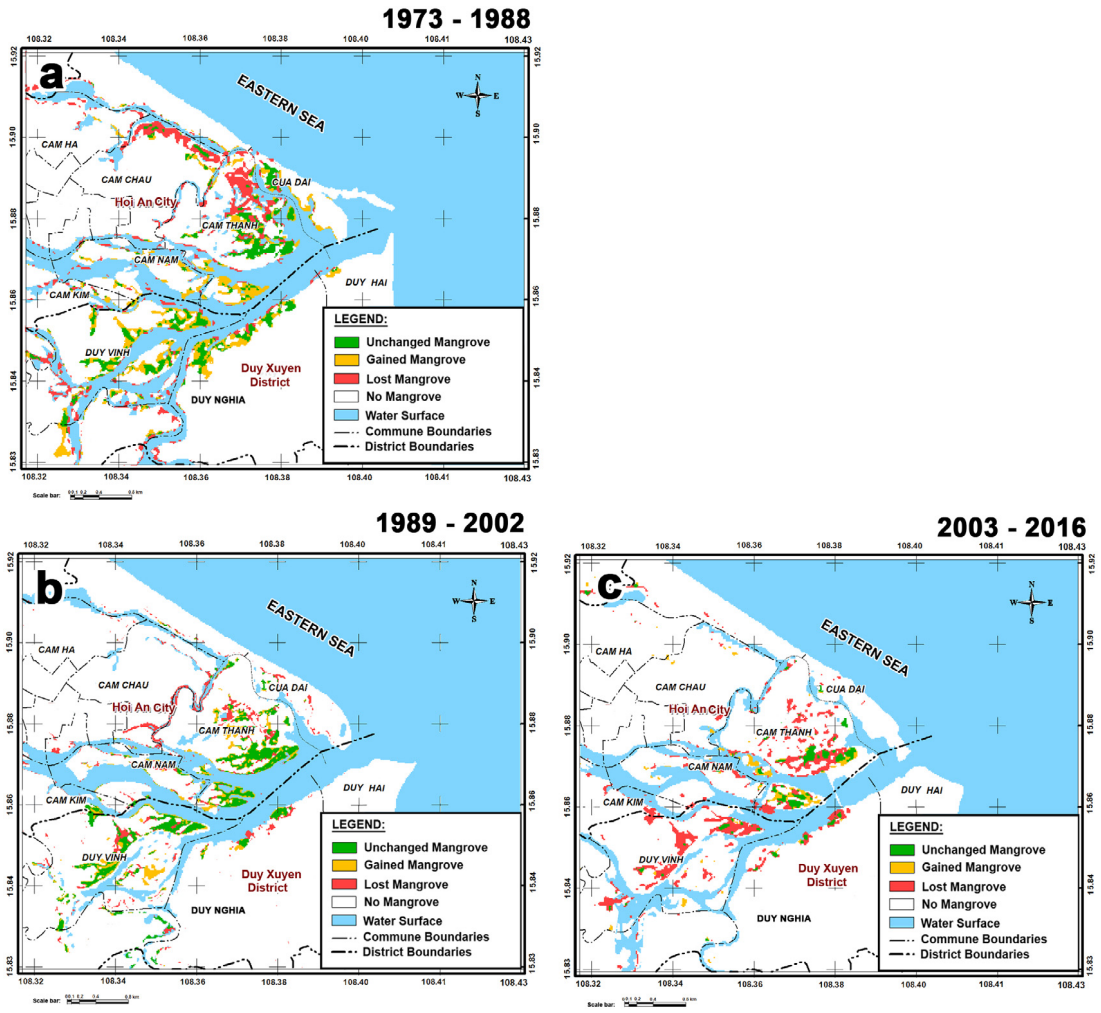

Fig. 5. The maps of mangrove temporal change in Cu Lao Cham-Hoi An Biosphere Reserve from 1973 to 2016: (a) 1973–1988; (b) 1989–2002; and (c) 2003–2016.

Impact of war (2.7% of responses): During the war, mangroves in Cu Lao Cham-Hoi An Biosphere Reserve played a vital role as a revolutionary and military base and mangroves grew stronger and more widespread during this period. The reason for declination of mangrove in the area during this time was essentially due to the impact of bombs used to attempt to destroy the revolutionary base.

The majority of responders to the survey were convinced that mangrove forests tended to decrease in the last 43 years. However, several local people had an opposite opinion. It is clear that these people who have a contrasting response are living in the areas of increasing mangrove so they just recognize the current status of the surrounding area without sensing the long term overview picture of the mangrove areas in the region. Other opinions were that before the year of 2013 mangrove area decreased but had shown increases continuously in the recent years due to the following reasons:

Efforts in management (15.28% of responses): In the most recent period, thanks to increased awareness of the mangrove ecosystem conservation and mangrove rehabilitation projects, mangrove area negative change has gradually stabilized. Besides, local authorities have implemented appropriate policies to encourage residents to properly utilize and protect their resources. For example, the Cam Thanh Commune People's Committee only allows local people to harvest *Nypa fruticans* leaves in two seasons: from February to April and from June to August to ensure proper harvesting techniques are used and *Nypa fruticans* (water coconut) can continue to grow well.

Nypa fruticans grows fast and regenerates (6.94% of responses): *Nypa fruticans* have numerous fruits pressed together into a sphere. *Nypa fruticans*' fruits will fall down when mature, disperse in the water flow, then sprout and grow very quickly.

Planting more for economic development (6.94% of responses): Planting more mangroves for building houses, handicrafts and ecotourism development are recently focused. The people of the community can earn extra income from these activities.

4. Discussion

The results of this study have established a significant database on mangrove species composition, documented the distribution and historical changes of the mangrove ecosystem in Cu Lao Cham-Hoi An Biosphere Reserve, central Vietnam and also identified the main reasons leading to the degradation of mangroves in the study area.

This study has documented eight new mangrove species in the inventory of the Cu Lao Cham-Hoi An Biosphere Reserve. These newly documented mangrove species for the ecosystem include: *Pluchea indica*, Mangrove trumpet tree (*Dolichandrone spathacea*), Bayhops (*Ipomoea pes_caprae*), Milky mangrove (*Excoecaria agallocha*), Sea hibiscus (*Hibiscus tiliaceus*), Large-Leafed Mangrove (*Bruguiera gymnorrhiza*), Shichito Matgrass (*Cyperus malaccensis*), and Pond apple (*Annona glabra*). These are newly

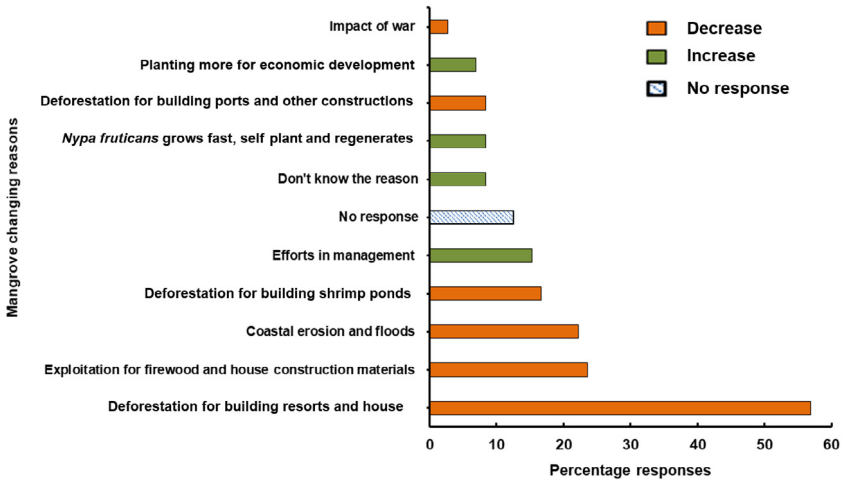

Fig. 6. The major causes of changes in mangrove area in Cu Lao Cham-Hoi An Biosphere Reserve from 1973 to 2016.

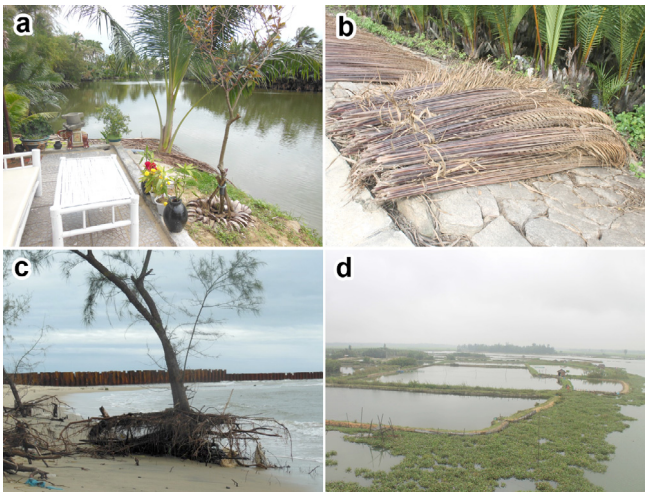

Fig. 7. Several major causes of mangrove ecosystem degradation (a) Deforestation for building resorts and house; (b) Exploitation for firewood and house construction materials; (c) Coastal erosion and floods; and (d) Deforestation for building shrimp ponds.

documented species to the mangrove flora of the study area as well as the mangrove forest in central Vietnam in general (Luong et al., 2014). However, compared to several previous studies on mangrove species composition in central Vietnam that were conducted at Lap An lagoon in Thua Thien Hue Province (33 species) (Pham et al., 2012), Gianh estuary in Quang Binh Province (23 species) (Duong and Nguyen, 2012), Phu Long in Cat Hai district of Hai Phong city (20 species) (Nguyen et al., 2013a), Quang Ninh coast (30 species) (Nguyen et al., 2013b), the diversity of species composition of mangroves ecosystem in Cu Lao Cham-Hoi An Biosphere Reserve coastal area (16 species) was not high.

In this study, Landsat image data was used for mangrove change assessment. The advantages of using this data source is its recognition by previous published studies for providing sufficient spatial resolution (30 m), multiple spectral bands and a historical storage database of satellite imagery from 1973 to the present (Nguyen et al., 2016). Overall accuracy and Kappa coefficients were used to evaluate the accuracy of classification of the satellite remote sensing images. The Kappa coefficient of the studied years demonstrated high accuracy with a range from 0.88 to 0.95. Compared to similar studies that also used Landsat satellite remote sensing images such as Mensah (2013) and Nguyen et al. (2016), the Kappa coefficients of this study had higher values, although lower than Pham's study in the Mekong Delta (Pham, 2012) which used higher spatial resolution SPOT images. Thus, Landsat satellite imagery data can be considered a trustful data source for assessing coastal mangrove ecosystem changes with relatively high accuracy.

According to senior residents (averaged age of 70 years old) living in the study area, the largest area of mangrove ecosystem in the study area has existed since they were old enough to remember. And, according to their grandparent's stories (the previous generation), the mangroves in this area originated from northern Vietnam whose inhabitants introduced mangroves to this area (Community surveys). The study results showed that the dynamic changes of the mangrove ecosystem over the last 44 years were significantly impacted by infrastructure and bridge building, which was one of main factors contributing to the loss of 256.6 ha of mangrove from 2003 to 2016. During the period from 2003 to 2016, the local authorities also attempted to plant an additional 45.9 ha. That in spite of this, the change of mangroves in the study area over last 44 years since 1973 tended toward a decrease (Fig. 8). Compared to the mangrove loss rate of several countries in Asia, the rate of mangrove decrease in central Vietnam was extremely high. Compared to previous studies conducted in the Sundarban World Heritage Site, the area with the largest mangrove population in the world, for the 40 years beginning in 1975 and ending in 2015, the percentage

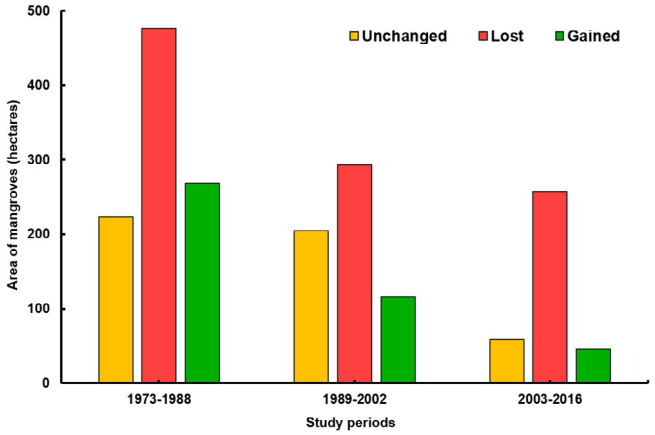

Fig. 8. Area of mangrove area lost, gained and unchanged from 1973 to 2016 (hectares).

of mangrove loss in the Sundarban World Heritage Site area was just roughly 4% of the total mangrove area (Mondal and Saha, 2018). Another study on the fluctuation of mangroves in Can Gio Biosphere Reserve, Vietnam, in the period from 1989 to 2014 reported that approximately 24% of mangrove area was converted to other land uses (Nguyen et al., 2016). A recent study on fragmentation of mangroves in Ca Mau peninsula, Vietnam, reported that approximately 35.4% of the mangrove area was also transformed to other land uses.

In general, however, thanks to management efforts in recent years, the mangrove area has gradually stabilized. In addition, mangroves provide livelihoods for local people such as materials for building houses and developing eco-tourism which have motivated local people to protect and preserve mangrove ecosystems. However, there are several limitations in the management, rehabilitation and development of mangrove ecosystems in the area. At present, the local authorities have become more aware of the important roles of mangrove ecosystems. Therefore, they have implemented several mangrove restoration and conservation projects as well as issued appropriate policies encouraging residents to practice sustainable exploitation and protection of mangroves. Due to increasing economic development demand, the exploitation of mangrove ecosystems' products is increasing. Several mangroves areas had been transformed into ecotourism facilities. Thus, an efficient management solution is required to prevent deforestation for future ecotourism and aquaculture development.

In summary, this study has contributed eight new mangrove species in the inventory of the Cu Lao Cham-Hoi An Biosphere Reserve. Especially, this study was regarded as the first study using multi-spectralsatellite remote sensing images to assess the current distribution status and historical changes of mangrove ecosystems in central Vietnam. One significant advantage of the study was combining resourceful methods such as standard ecology surveys, sociological methods and multi-temporal satellite remote sensing image analysis in order to assess the historical change of mangrove ecosystems. Thanks to an interdisciplinary approach, this study also helped to identify the main reasons which have led to mangrove ecosystem degradation over the last 44 years in the study area. This study's documentation of the recent trend toward stabilization of the area of the mangrove ecosystems through a combination of sound management policies and increased public awareness is, hopefully, a positive indicator for the future of this important resource.

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